§18. Transport Analysis of High Density Plasmas with Internal Diffusion Barrier in Toroidal Helical Plasmas

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The understanding of the turbulence-driven transport and the improved confinement (transport barriers) is the key issue in fusion research. Many kinds of the improved confinement mode in the core plasma of toroidal helical plasmas have been reported; e.g., the e-ITB with the strong positive radial electric field. The radial transition of E_r was predicted to induce the internal transport barrier due to the shear of the radial electric field in the helical plasmas. The transition of E_r was found on the Compact Helical System (CHS), and the improvement of confinement was found inside of the transition point for E_r. Observations on Wendelstein7-AS (W7-AS), LHD and the other experiments followed. On the other hand, the Internal Transport Barrier (IDB) in LHD was recently discovered with the strong gradient of the density in a super dense core (SDC) plasma when a series of the pellet is injected. We present the transport model to explain the IDB. The theoretical model for the IDB observed in LHD is shown. The mechanism, which is based on the transport reduction due to the shear of the radial electric field, is newly examined in the formation of the IDB. In the case of the particle fuelling, the density rapidly increases. Therefore, the ion temperature temporally decreases and the positive gradient in the T_i profile is found to appear. From the ambipolar condition to determine the E_r profile, the positive E_r is found. As the result, the strong gradient of E_r and the reduction of the anomalous particle diffusivity can be shown.

For the case of the IDB plasma, the transport modeling is done. The one-dimensional transport analysis for the LHD-like plasma has been performed. To simulate the pellet injection, we use the parameter S_p of the particle source. This parameter S_p has a distribution as $S_p=S_{p0}\exp(-(r/(0.2a))^2)$ and is set to have a value from the initial time t=0 to 1ms. We set the pulse of the particle source as $S_{p0}=10^{23}\mathrm{m}^{-3}\mathrm{s}^{-1}$ for 0<t<1ms and $S_{p0}=0\mathrm{m}^{-3}\mathrm{s}^{-1}$ for t>1ms. The rapid change of the gradient in the density profile at t=10ms can be found at $\rho = \rho_T(\approx 0.2)$ in Fig. 1, where $\rho=r/a$. The parameter ρ_T represents the location of the transition from the positive E_r to the negative E_r at 10ms. When the value of the density increases with the particle fuelling in Fig. 1, the value of the ion temperature decreases because the value of the pressure is temporally constant. We can show the much steeper gradient ($|E_r'|\sim 100\mathrm{kVm}^{-2}$) of the radial electric field at the point ρ_T at t=10ms than that at t=1ms. The time 10ms is roughly the typical time scale during which the radial transition of E_r is formed in the parameter regime examined here. A clear reduction of the anomalous particle diffusivity D_a is found at the transition point $\rho=\rho_T$ due to the strong gradient of E_r compared with

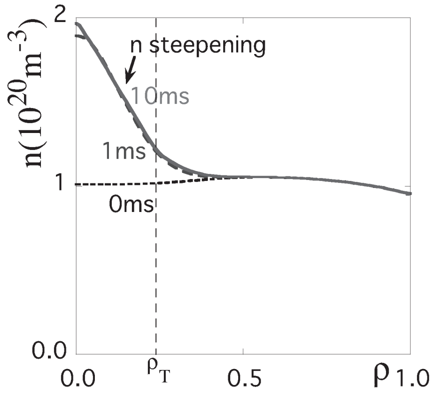

Fig. 1 Temporal evolution of the density profile

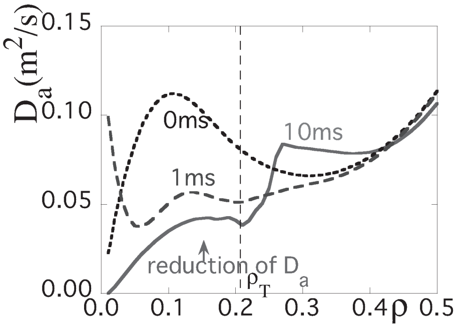

Fig. 2 Temporal evolution of the anomalous particle diffusivity D_a

the region $\rho>\rho_T$ at 10ms in Fig. 2. In the region $\rho<0.3$ at the time 10ms, the neoclassical diffusivity D_{NEO} $(=-\Gamma^{na}/n')$ is found to be much smaller than the absolute value of the effective anomalous particle diffusivity and is $|D_{NEO}|<0.01\mathrm{m}^2\mathrm{s}^{-1}$, where Γ^{na} is the neoclassical particle flux. In the core region, the slightly negative value for the effective neoclassical particle diffusivity D_{NEO} and the particle neoclassical pinch are obtained at the time 10ms. The value of E_r can be roughly derived by the equation $E_r=T_i(n'/n+C_iT_i'/T_i)/e$ in the parameter region examined here ($T_e\approx T_i$). Note that the contributions to E_r from the gradients of n and T_i are different by the factor C_i, where $C_i\approx 3$. The positive E_r can be obtained because of the sufficient positive T_i' in the region $\rho<\rho_T$. Therefore, the strong gradient of E_r can be obtained. It is emphasized that the barrier formation still occurs after the particle fuelling. If we set much smaller value for S_{p0}, $S_{p0}=2\times 10^{22}\mathrm{m}^{-3}\mathrm{s}^{-1}$ than that ($S_{p0}=10^{23}\mathrm{m}^{-3}\mathrm{s}^{-1}$) in this calculation, we can not find the steepening in the density gradient, because the gradient of E_r after the pellet fuelling is not large enough. It is shown that there is a threshold value for S_p to form the barrier with respect to the particle confinement in the density profile.

1) S. Toda and K, Itoh: Plasma and Fusion Research, in press.